TRW: Proving that Production MBE is not an Oxymoron

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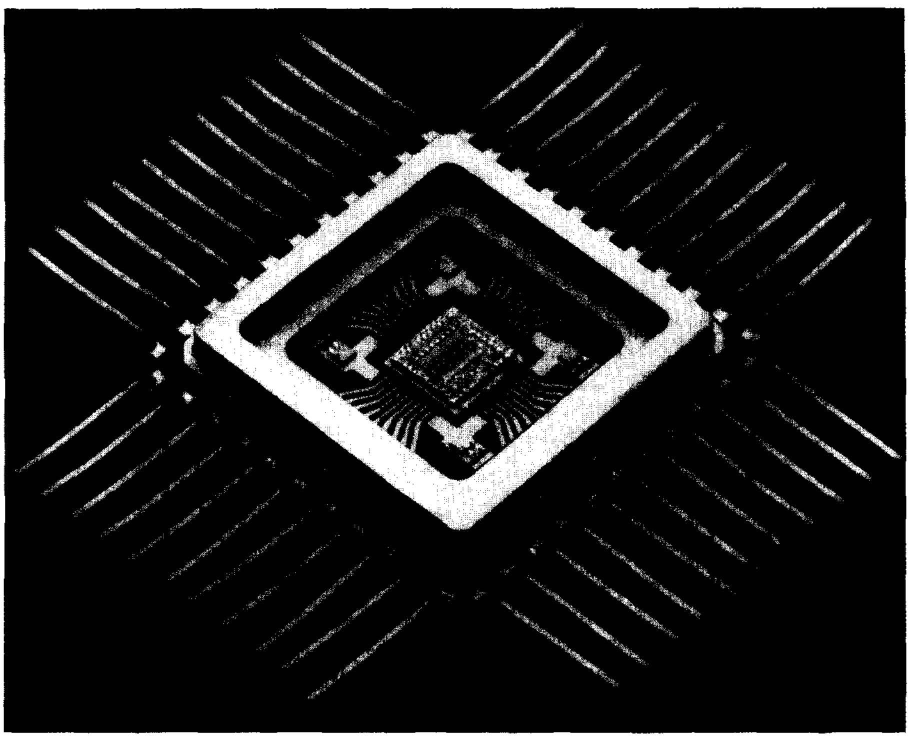
TRW's Electronic System & Technology Division within the Space and Electronics Group (Redondo Beach, California, USA) keeps a low profile. Yet they're literally moving millions of remarkably high quality HBT and HEMT devices through their III-V fab. How are they keeping up with the demand? Believe it or not, through four production MBE machines that consistently produce yields well into the 90% range.

TRW's MMIC fabrication facility typically moves over 450 different types of MMICs every year. The current mix approximates 10% MESFETs, 50% HEMTs and 40% HBTs. Early on in the epi game, TRW chose a given production course for HBT and HEMT devices and stuck to it. The epi leader chose to use VGF substrates (as opposed to LEC material) and MBE with beryllium doping (when others went the lower yielding carbon-doped MOCVD route). When TRW presenters stand up before their peers at conference after conference with their consistently conclusive reliability data, proof of high yields, and a steady stream of new offerings, they still take a lot of flak for going the MBE route.

Yet, anyone who sees the data necessarily must become a TRW "flak fighter" because TRW is proving, conclusively, that production MBE is obviously not the oxymoron some MOCVD advocates would like one to believe.



In its automated GaAs MMIC manufacturing facility in Redondo Beach, Calif, TRW is producing monolithic analog-to-digital converter (ADC) MMICs such as this 4-bit ADC.This ADC MMIC has a wide input bandwidth of more than 2 GHz, and is appropriate for use in applications such as communications, direct RF downconversion, and radar warning/guidance systems.

Try this for starters: TRW's HBT MMICs on 3-in MBE wafers, grown in-house, with yields over 98% on the 25 000 HBTs per wafer, priced under $1 each for packaged and fully tested chips. According to Jerry Neal of RF Micro-Devices (RFMD, Greensboro, North Carolina, USA), the primary design house that receives such a shipment from TRW with increased regularity, "we're literally moving millions of them." In turn, as RFMD's customers, which are primarily cellular telephone manufacturers like Qualcomm Personal Electronics (San Diego, CA, USA), report back incredible reliability and the fact that TRW's reproducibility record is flawless, the end customers' orders just keep going up, up, and up.

"It's been a long time coming, but we finally made it," says Jerry, sporting a very big smile.

There are, of course, many people behind the scenes of this MBE success story, but one of the key TRW drivers has been Dwight C. Streit, PhD, assistant manager of the Microelectronics Product and Technology Development Department and manager of the Advanced Materials Section in TRW's RF Products Center. Dwight wears many hats at TRW. He is also principal investigator for two research and development projects related to III-V materials and MMIC HEMT-HBTs. His primary research interest is the relationship between material characteristics and device performance, and his work has dealt with both HEMT and HBT material development and device design. Among his many accomplishments, Dwight is a TRW Technical Fellow and a three-time recipient of the TRW Chairman's Award for Innovation.

"My primary job, however, is to pay the rent by being in a production mode. I don't think people realize the volume of wafers that are done here," Dwight says. One product that's moving especially well is the set of four HBT chips for code division multiple access (CDMA) transmissions that has captured the interest of several major cellular handset makers. The overall chip set design is a cooperative effort between TRW, RFMD, and CDMA-developer Qualcomm Personal Electronics, a joint venture with Sony and considered to be one of the most important leaders in digital compression technology. RFMD provides the designs and marketing expertise whereas TRW does all of RFMD's MMIC chip fabrication.

According to Dwight and RFMD's Jerry Neal, business is literally booming. "We're shipping tons of these chips," says Jerry. Will we see them soon in CDMA handsets? "Very soon," say both Jerry and Dwight, and from a growing number of vendors. Dwight points out the reality, however. "People will believe that TRW HBT is a serious contender in the wireless market when they can go into Radio Shack and buy a cell phone that has a TRW HBT in it."

Unfortunately, unless you take your new phone apart, you'll likely never know if it's a TRW part or not. TRW and RFMD will know, however, because profits will continually rise for the two companies.

TRW is using MBE for high volume production of both HBT and HEMT MMIC devices. Using MBE for active layer production, the company has produced MMICs on three-inch wafers (containing 25 000 HBTs per wafer) with yields in excess of 98 percent.

Breaking HBT $1 barrier

The TRW products that broke the $1 HBT barrier are three general purpose RF amplifier IC gain blocks packaged in small outline IC eight pin SOIC surface mount packages for low cost, high volume manufacturing. All three devices are unconditionally stable, internally matched for 50 ohm inputs and outputs, and easily cascadable. The key to breaking the price barrier is the extremely small die sizes referred to above.

TRW's long track record is another reason. TRW came into prominence as an early contributor to the US government's MIMIC Program with its epi work in MIMIC Phase One (and, incidentally, was the MIMIC contractor with the distinction of delivering the first MIMIC circuit, and it was an HBT!) and the company remains a leading edge producer for government applications.

InP HEMT Work

In a Late News Section presentation at IEDM in December in San Francisco, authored by H. Wang, R. Lai, D.C.W. Lo, D.C. Streit, M.W. Pospieszalski and J. Berenz, TRW announced their 140 GHz MMIC Low Noise Amplifier (LNA). The achievement represented the highest frequency amplifier ever reported using three terminal devices, demonstrating a gain performance of 9 dB at 142 GHz for a two stage design, which is in line with current InP-based HEMT technology.

Monolithic HEMT-HBT Integration

Perhaps the most exciting device news out of TRW recently, and likely to follow on the heels of the cellular chip sets in commercial popularity, is the incorporation of MMIC HEMTs and HBTs in the same microwave circuit. Specifically, it is the first successful monolithic integration of pseudomorphic InGaAs-GaAs HEMTs and GaAs-AlGaAs HBTs in the same microwave circuit using selective MBE and a novel merged HEMT-HBT process technology. The resulting 0.2 micron gate-length HEMTs and 2 micron emitter-width HBTs have excellent dc and microwave characteristics with no observed degradation in device or circuit performance due to the additional growth and process steps required to achieve HEMT-HBT MMIC integration.

A paper on the achievement, co-authored by Dwight Streit, Donald Umemoto, Kevin Kobayashi and Aaron Oki is in the April issue of IEEE Transactions Electron Devices (Log Number 9409049). Quoting from the conclusion of that paper, which underscores the projected use of the chip, "The motivation for integrating HEMT and HBTs on the same chip is to produce microwave

In its automated GaAs MMIC manufacturing facility in Redondo Beach, Calif, TRW is using next-generation metallization equipment, such as this E-beam evaporator, to deposit precision layers of metal, under vacuum, onto three inch GaAs wafers.

TRW GaAs (HBT-MMICs (frequencies up to 23 GHz) HEMT MMICs (frequencies up to 94 GHz) for commercial and military applications. In the photo, a technican loads gallium arsenide wafers into a crystal carrier for insertion into the high-temperature wafer processing ovens shown at left.

circuits with performance levels unattainable using either device technology alone. The design opportunities when both HEMT and HBT devices are available on the same chip are endless, especially when combined with THz Shottky diodes and HBT base-collector PIN diodes. For instance, monolithic integration of microwave and digital functions can significantly improve receiver performance. Novel circuit designs such as TTL-controlled phase shifters, low-noise high-power TR modules, and FMCW single-chip radars that incorporate HBT VOCs with HEMT LNAs are all possible using monolithic integration of high-performance HEMTs and HBTs."

VGF substrates and Intevac MBEs

TRW is using vertical gradient freeze (VGF) GaAs substrates from AXT. They are also doing some excellent InP HEMT work and were fortunate enough to receive a large shipment of InP wafers from Sumitomo the day of the Kobe earthquake. Their four MBE machines are all Intevacs. Although Intevac sold everything to EPI, Londonderry, New Hampshire, USA, over a year ago, Dwight reports that EPI is "doing a good job supporting all of the spare parts and everything we need from the old Intevac."

He continues, "Even though those Intevac machines are single wafer, which is a drawback that limits our throughput, we can easily supply all the material that our production line can handle, and that's the key. There have been a lot of "Doubting Thomases" here, with good reason, because it's taken awhile to understand all the reliability aspects of the equipment. But now we really know the failure mechanisms and modes, and we replace parts before they fail. If we've determined that a certain part has a mean time to failure (MTTF) of so many microns of growth, we replace it before that MTTF so the probability of its failing during a growth cycle is pretty slim."

Proof of success is in the track record for device reliability. TRW has logged over 1 million hours of lifetime testing already, and their reliability data has been well documented and continues to be available in the public domain, an accomplishment MOCVD evidently has yet to claim.

What's the main message to get across to those who still haven't the faith in MBE for large volume, truly low cost production? "That MBE is viable not only for HEMT growth but also for HBT growth and it has all the same advantages as far as uniformity and reproducibility," emphasizes Dwight. "I believe people gave up on it too soon for HBTs. In reality, our designers here at TRW don't care about the material that much. They do in the sense that if you're driving your car, you care about the engine. But in reality, when the hood's closed, you don't think about it. In fact, they're tickled pink that everybody else is in MOCVD because those people aren't really producing. MOCVD is having a lot of trouble, and the trouble isn't really being publicized."

The consensus of those who take MBE seriously as a top quality production tool is that the materials scientists focus on what the device people really need, as opposed to experimentation with the goal of simply publishing the latest, greatest performance on a small scale. "That's one of the other things that's different here. All of the profiles used at TRW came out of the materials group in cooperation with the device people. But then, that's what the materials IR&D (Innovative R&D) was for: to design device profiles, to grow them, to process them without getting a whole lot of people excited about it until we see how it works," Dwight explains.

Keys to such high yields

90% yields? "It's actually much better than that," says Dwight. "There are two keys: one is we can actually tell before we ever deliver a wafer whether it's good or not. In reality, our growth yield is probably about 98%. But then we have analysis techniques that tell us whether or not the device is intrinsically good before we ever ship it to the production line. And we literally don't give the production line anything that's not going to work. Last year, I think they had one wafer that there was a malfunction in a system that we didn't catch, and for some reason our photoreflectance didn't catch it. It was in the emitter contact. So you had one wafer all year long where there was something wrong intrinsically in the material. And because everything is done in-house, we were able to track it back and find out that there were actually three or four wafers in a row and stopped the other ones before they were processed."

TRW has an especially good production control system, he goes on to explain. "We document everything. We do a lot of SPC (statistical process control) with an entire room where the walls are covered with SPC charts. For HBTs, we track a half dozen different parameters from the materials side. We track aluminum composition, the built-in field at the base emitter junction as determined from photoreflectance, resistivity, doping levels in the different layers, and thickness, and the result is that we can put those plots out for the last thousand wafers and really see exactly what our long term trends are. By doing so, we can see that the spread is getting tighter and tighter. Essentially, we're constantly developing the techniques to prove these things. By keeping everything in-house, we have direct control of everything that happens from the time we receive the substrates, which is the only thing we depend on outside people to provide. Our whole premise is that performance and reliability are really built into the profile."

Dwight Streit contends that close communication between TRW's materials and device people is a primary reason they have been so successful, and that communication is more easily facilitated when everything is under the same roof. Can it be done with an outside epi supplier? "If you have a very closely coupled relationship with a vendor, you can establish the same kind of relationship, but it's tougher if they're feeding multiple houses. We only have one job here and that's to feed our production line. If they falter because of our material, we hear it across the street, believe me," Dwight confesses.

"Actually, I think there are a few reasons why we've been pretty lucky at getting consistency and that is because in the materials area, we're unique. Historically, at other operations you would have a HEMT department that has their own materials people and their own processing people, and you have an HBT department that has their own materials people, and they don't talk to each other. In some cases, there are facilities with a HEMT machine and an HBT machine practically side by side and the growers never talk to each other. Our operation is different in that everything that has to do with epitaxial material, substrate acquisition, material growth, materials characterization, is all in the same group, so the same people do HEMTs and HBTs. They grow the material and analyze the material. You don't throw it over the fence to a materials analysis lab in another department and wait a couple of weeks to get results," he explains, noting that the entire charter of his center, which has a total of 620 people in it, is to do nothing but build and package GaAs chips.

Next on the agenda

The hub of the TRW GaAs effort is the D-1 building that was erected during the MIMIC Program, but the center itself also has both microwave and digital designers because TRW also does a considerable amount of digital in GaAs. "The digital HBT is a very, very hot product. I think over the next three to four years, you're going to see an incredible amount of chips out there in the commercial market that are digital HBTs. We also have an ARPA program to do a digital HBT foundry," reports Dwight. "I attended the reviews as the program came on board and, initially, everyone was concerned about the material, but now our ARPA customers are very, very happy. It's not just device performance now, it's circuit performance that counts."

Advent of HBT for ADC

In fact, one area of near-term growth will be analog and digital, or mixed signal HBT products. Brian Wong, assistant manager of the High Speed Digital and Analog Products Department in TRW's Digital Products Center, views GaAs HBT technology as ideal for the development of wideband, precision circuits such as analog-to-digital converters (ADC). "As the push for wider bandwidths with higher precision continues, the emergence of the GaAs HBT technology is destined to challenge silicon bipolar's domination at the high end of the analog market," says Brian. TRW is planning to release the first GaAs ADC on the market in the third quarter of this year: a monolithic 4-bit, 1.25 Gsps ADC with near theoretical performance. This chip, currently in beta production, contains an integrated wideband amplifier and sample-and-hold. TRW's next generation 1 micron GaAs HBT technology will develop even higher performance mixed signal circuits. We are currently developing 8-bit, 1.75 Gsps ADCs to enable the direct digitization of wide bandwidth signals for various high-end applications" states Bert Oyama, technical manager on this development.

The bottom line

The question of whether there's a GaAs HBT driving the product or not matters greatly to our III-V community but it doesn't matter to anyone else up the foodchain as much as price and performance. As Dwight Streit puts it, "The product user is concerned with the same things as the manufacturer: performance, cost, and reliability, and TRW enables the manufacturers and users to achieve these goals."

Silicon chips challenge the GaAs market

The SIEGET line (Siemens Grounded Emitter Translator) with cutoff frequencies exceeding 25 GHz has forced its way into one of the preserves of GaAs ICs. Manufactured using B6HF technology, the chips now comprise gate arrays for signal processing at rates up to 10 Gbit/s as well as individual transistors. "The technical superiority of these devices is seen in their higher output and lower noise levels than existing solutions; making them particularly attractive for the new frequency ranges around 2 GHz", says Siemens.

The three transistor types currently available have different areas of application. The BFP 405 can be used for oscillators up to 12 GHz and amplifiers with low noise levels at low currents ($I_{cmax} = 12$ mA), thus meeting the requirements of mobile applications. The BFP 420 is a transistor with a wide range of uses, notably in oscillators up to 9 GHz, and amplifiers with low noise and high amplification levels, while the BFP 450 ($I_{cmax} = 12$ mA) is intended for driving stags. At a supply voltage of 3 V and a frequency of 1.9 GHz, it provides a typical output of +19 dBm.

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